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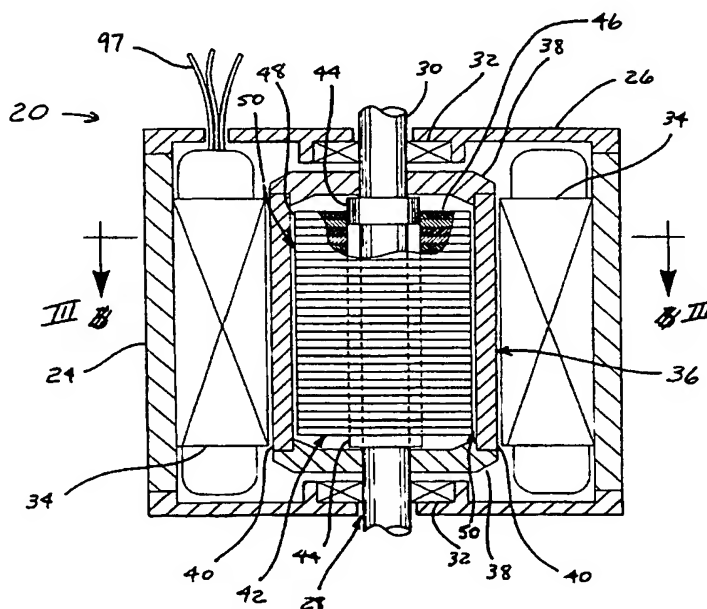
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- (71) Applicant: **DELPHI TECHNOLOGIES, INC.** [US/US]; Legal Staff - Mail Code: 480-414-420, P.O. Box 5052, Troy, MI (US). For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: BRUSHLESS MOTOR WITH REDUCED ROTOR INERTIA



(57) Abstract: A direct current electric motor (20) has the following features: a housing (22), a stator (34) being affixed to the housing (22); a reduced inertia rotor (36) being located in a central cavity of the stator (34). The rotor (36) includes a shaft (30), a permanent magnet ring (40) that is formed by two magnets (52, 54) being affixed in a radially spaced manner from the shaft (30), and a rotor core (42) being located between the shaft (30) and the magnet ring (40), wherein the rotor core (42) is rotationally de-coupled from the shaft and the magnet so that the rotor core (42) remains stationary with respect to the rotatable shaft (30) and the magnet ring (40).

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BRUSHLESS MOTOR WITH REDUCED ROTOR INERTIA

CLAIM OF PRIORITY

5 This application claims priority under 35 USC § 119(e) from provisional application serial no. 60/170,559 filed on December 14, 1999, entitled "Actuators for Use with Electric Disc Brake Calipers".

TECHNICAL FIELD

10 The present invention relates to direct current electric motors and in particular to rotors for direct current electric motors.

BACKGROUND OF THE INVENTION

15 Mechanical linkage and hydraulic pressure operated controls for vehicles are well known in the art, and generally comprise control input devices operated by a user such as steering wheels, shift levers, and foot pedals which are directly interlinked with various vehicle controls individually or by combinations of mechanical push rods, gears, cables, or hydraulic pressure lines. Such controls have been utilized in vehicles such as automobiles and trucks since the inception and initial
20 manufacture of such vehicles. As technology has advanced, today's vehicles regularly incorporate computers in various forms to assist in vehicle control. These computers can rapidly acquire various objective input data, analyze the data, and adjust the vehicle controls based on the data analysis to more readily optimize the operation of various vehicle systems and controls. As a result of the rapid computational power of
25 the computers the computers can issue control commands at a much faster rate than older technology mechanical system configurations can respond. The requirement for increased control response times were initially felt in the aerospace industry where modern aircraft have evolved from the use of mechanically linked controls to electrically operated controls in a concept commonly known as "fly-by-wire".

30 Other industries such as the auto industry are now also in need of such rapid response capability in the control systems of such vehicles. One such system desired to be adaptable to electrically operated controls on many automobiles requiring rapid control response are anti-lock brake systems ("ABS"). The concept of an ABS on vehicles is to permit the user to apply a constant pressure to the brake

pedal which the braking system senses whether or not the wheels are in a skid to provide maximum braking force to the wheels while the wheels are turning and to release the braking force when a skid is sensed. Such cycling between different braking states occurs rapidly to minimize the braking distance of the vehicle while preventing the vehicle wheels from locking in a skid. To provide the desired and optimum actuation of this type of system requires new modes of system actuation other than prior art mechanical means. Electric servos and DC electric motors with improved response times readily lend themselves to integration with the onboard computers and vehicle systems.

Some controls such as those used with the above-mentioned ABS require rapid cycling of the servos or motors wherein the desired cycling times are in the range of milliseconds. The cycling rates of these control motors are a function of a number of factors, one of which is motor size. Larger motors generally require more time in which to cycle since the moving parts of the motor are generally of a greater mass and correspondingly have a larger inertia which must be overcome to either start or to reverse direction. Because of the torque and power requirements to provide sufficient control forces such as those required on vehicle brakes, current motor designs while a significant improvement over mechanical linkage, still do not optimally lend themselves to applications wherein there is also a requirement for rapid cycling of the control motor.

Prior art motor designs typically include a stator comprising a series of electrical windings to generate magnetic fields that in turn induce the rotation of a rotor. The rotor is generally of a relatively high mass wherein the rotors generally comprise a shaft upon which is mounted a high-density magnetic core with a plurality of permanent magnets affixed about its periphery. The large mass of the rotor results in a large rotational inertia, which is then difficult to reverse or cycle at the desired high cycling rates. Thus, there is a need for a DC electric motor that is capable of delivering greater torque with reduced rotational inertia to facilitate rapid control cycling.

SUMMARY OF THE INVENTION

One aspect of the present invention is a direct current electric motor including a housing with a stator that further includes a plurality of electrically conductive windings. The stator defines a central cavity in which a rotor is rotatably

mounted therein. The rotor comprises a shaft and at least two magnets affixed in a radially spaced manner from the shaft and includes a rotor core between the shaft and the magnets wherein the rotor core is rotationally de-coupled from the shaft and the magnets.

5 Another aspect of the present invention is a rotor for a DC motor. The rotor includes a shaft and a plurality of magnets rotationally coupled to the shaft and radially spaced there from the shaft and the magnets define a cannular cavity therebetween in which is positioned a rotor core. The rotor core is rotationally de-coupled from the shaft and the magnets.

10 Yet another aspect of the present invention is a direct current electric motor capable of rapid reversal rates. The motor includes a housing and a stator affixed within the housing wherein the stator defines a substantially cylindrical cavity having a central axis. A rotor is journaled to the housing for rotation about the central axis and is positioned within the cylindrical cavity. The rotor includes a shaft having
15 an axis of rotation coincident with the central axis and a plurality of magnets radially spaced from the shaft and rotationally affixed thereto. The shaft and the plurality of magnets define a cannular cavity within which a rotor core is positioned and is rotationally de-coupled from the shaft and the magnets.

20 Still another aspect of the present invention is a method for minimizing the rotational inertia of an electric motor rotor. The method comprises the steps of providing a rotor shaft; mounting a plurality of magnets about the shaft in a rotationally coupled manner; and mounting a rotor core about the shaft and within the magnets in a rotationally de-coupled manner.

25 These and other features, advantages, and objects of the present invention will be further understood and appreciated by those skilled in the art by reference to the following specification, claims, and appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

30 Fig. 1 is a perspective view of a direct current electric motor embodying the present invention and integrated into a generic control mechanism.

 Fig. 2 is a longitudinal sectional view of a DC electric motor incorporating a reduced inertia rotor.

 Fig. 3 is a plan sectional view of the DC electric motor of Fig. 2 taken along the line III-III of Fig. 2.

Fig. 4 is an enlargement of the cross-sectional view of Fig. 3 showing the rotor and further illustrating magnetic flux lines.

DESCRIPTION OF THE PREFERRED EMBODIMENT

5 For purposes of description herein, the terms “upper”, “lower”, “right”, “left”, “rear”, “front”, “vertical”, “horizontal”, and derivatives thereof shall relate to the invention as oriented in Fig. 2. However, it is to be understood that the invention may assume various orientations and step sequences, except where expressly specified to the contrary. It is also to be understood that the specific devices and processes
10 illustrated in the attached drawings, and described in the following specification are simply exemplary embodiments of the inventive concepts defined in the appended claims. Hence, specific dimensions and other physical characteristics relating to the embodiments disclosed herein are not to be considered as limiting, unless the claims expressly state otherwise.

15 Turning to the drawings, Fig. 1 shows a DC electric motor 20, which is one of the preferred embodiments of the present invention incorporated into a vehicle control system.

Direct current electric motor 20 is connected via an interface 97 typically comprised of electrically conductive wires for transmitting electrical signals
20 and electric power to the motor 20 from a controller 96. Controller 96 can be a computer processor or similar controller that issues start, stop, and directional commands to motor 20. The output of motor 20 generally takes the form of rotational torque transmitted by rotating shaft 30 which delivers its rotational torque to rotary-linear converter 98. Converter 98 converts the rotational torque of shaft 30 to a linear
25 force. Such converters are well known in the art and include, but are not limited to, combinations of planetary gears, rack and pinion mechanisms, etc. The linear force output of rotary-linear converter 98 is transmitted via linear drive linkage 99 to a linear driven mechanism 100. As an example, linear driven mechanism can be a disc brake caliper for a vehicle brake. Those skilled in the art will recognize that different
30 combinations and applications of rotary-linear converters and linear driven mechanisms are possible and contemplated within the disclosures described herein.

Referring now to Fig. 2, electric motor 20 is shown in longitudinal cross-section to illustrate the internal components and the arrangement thereof. Direct current electric motor 20 includes a housing 22, which is typically comprised of a

cylindrical body 24 and end plates 26 at each end thereof. Each end plate 26 has a centrally located aperture 28 to permit a driveshaft 30 to extend therethrough to deliver the power output of motor 20 to rotary-linear converter 98 as previously discussed with respect to Fig. 1. Driveshaft 30 is freely rotatable with respect to housing 22 and is mounted in apertures 28 by shaft support bearings 32. Shaft support bearings 32 can be any one of known bearing constructions incorporating ball bearings, roller bearings, magnetic bearings or other low friction combinations to permit shaft 30 to freely rotate within housing 22.

A stator 34 comprising windings of a plurality of electrical conductors is affixed to the inside periphery of housing 22. Stator 34 is of a construction that is well known within the direct current electric motor art, and thus its construction and assembly although not described in detail herein will be readily understood by those skilled in the art. The control signals from controller 96 are generally transmitted to stator 34 by interface wiring 97. Stator 34 defines a substantially cylindrical cavity within electric motor 20.

A rotor assembly 36 is positioned within the cylindrical cavity defined by stator 34. Rotor assembly 36 includes driveshaft 30, which extends along the central longitudinal axis of motor 20 and is rotationally journaled therein as previously described. A permanent magnet ring 40 comprising a plurality of permanent magnets 52 and 54 are mounted about the periphery of driveshaft 30 and radially spaced therefrom by end caps 38. The outer diameter of the plurality of permanent magnets 40 is slightly smaller than the diameter of the cylindrical cavity defined by stator 34 thereby insuring that rotor assembly 36 can freely rotate within the central cavity defined by stator 34. Driveshaft 30, end caps 38 and permanent magnet ring 40 define a cannular cavity that houses rotor core assembly 42. Rotor core assembly 42 is mounted on shaft 30 by bearings 44 such that rotor core assembly 42 can freely rotate about shaft 30 and is substantially rotationally de-coupled therefrom. Rotor core bearings 44 can again be a bearing configuration including ball bearings, roller bearings, magnetic bearings or any other commonly known bearing configurations minimizing the frictional interface between rotor core 46 and driveshaft 30. The diameter of rotor core 46 is minimally smaller than the inside diameter of the permanent magnet ring 40 radially spaced from driveshaft 30, thus defining an air gap 50 between rotor core 46 and permanent magnet ring 40. Rotor core 46 comprises a solid mass or alternatively a plurality of wafer-like laminates 48

which are bonded together to form the cylindrical rotor core 46. The solid core mass or each wafer-like laminate 48 is fabricated from an electrically conductive and magnetically permeable material such as steel. However, each laminate 48 is coated with a non-conductive coating such that each laminate 48 is electrically insulated from its next most adjacent laminate.

Fig. 3 illustrates a cross-section of DC electric motor 20 illustrating the generally concentric arrangement of its various elements wherein cylindrical body 24 of housing 22 is the outermost element. Stator 34 is attached to the internal periphery of cylindrical body 24 and extends about the entire internal periphery. Permanent magnet ring 40 of rotor assembly 36 is comprised of a plurality of permanent magnets 52 and 54 arranged such that magnet polarity of adjacent magnets are different here illustrated with four permanent magnets wherein north poles 52 are separated by permanent magnet south poles 54. While any number of permanent magnets can comprise permanent magnet ring 40, only four such magnets are illustrated herein for the sake of clarity and simplicity. Rotor core 46 is sized and positioned within permanent magnet ring 40 in such a manner to minimize air gap 50 therebetween. At the center is rotor core bearing 44 mounting rotor core 46 to shaft 30 in a rotationally de-coupled manner.

Those skilled in the art will recognize from Fig. 4 that the alternating polarity of magnets 52 and 54 have magnetic flux lines schematically presented as outwardly pointing arrows 53 representing north pole flux lines and inwardly pointing arrows 55 representing south pole flux lines with the magnetic flux present in rotor core 46 schematically illustrated by flux lines 57.

In operation, as a directional start control signal is received by motor 20 on interface wiring 97, the windings of stator 34 are energized in a manner known in the art to induce the desired directional rotation of rotor assembly 36 to deliver a desired torque to rotary-linear converter 98. Because of the generally short linear actuation distances required by linear driven mechanism 100, same-directional rotation of motor 20 occurs only for a very short time. For example, motor 20 is designed to operate at a rotational speed of approximately 5,000 rpm and since only approximately 20 revolutions of rotor assembly 36 are required to produce the desired linear travel of mechanism 100, motor 20 need operate in a single direction for only milliseconds at a time. Since rotor core 46 is rotationally de-coupled from shaft 30 by bearings 44 and with the short directional cycle time of motor 20, rotor core 46

remains substantially stationary within motor 20. Thus, only the mass of shaft 30, end caps 38, and permanent magnet ring 40 need be accelerated to its operational rotational speed.

5 With the decreased mass induced into rotation by stator 34, rotor assembly 36, with a smaller rotational inertia, is accelerated at a faster rate. Correspondingly, rotor assembly 36 can be cycled in an opposite direction in a reduced cycle time from that of a standard rotor where the entire rotor assembly, including the rotor core, must be accelerated, decelerated and then changed direction to be accelerated in the opposite direction.

10 Thus, those skilled in the art will readily recognize that by decoupling the rotor core from the rotor shaft electric motor 20 exhibits a vastly improved control cycle time in applications such as those required by, for example, anti-lock braking systems, or other similar applications. The function of the rotor core is to provide a path for the magnetic flux associated with permanent magnet ring 40, and this
15 function does not require the concurrent rotation of rotor core 46 with permanent magnet ring 40. While optimally permanent magnet ring would be bonded to core 46 for maximum electrical performance, the air gap 50 between core 46 and permanent magnet ring 40 results in some minor adverse performance degradation. The degradation is minimized by minimizing the air gap between rotor core 46 and
20 permanent magnet ring 40. The minimal degradation caused by air gap 50 is greatly offset by the reduced rotational inertia when rotor core 46 is rotationally de-coupled from shaft 30.

The above description is considered that of the preferred embodiments only. Modifications of the invention will occur to those skilled in the art and to those
25 who make or use the invention. Therefore, it is understood that the embodiments shown in the drawings and described above are merely for illustrative purposes and not intended to limit the scope of the invention, which is defined by the following claims as interpreted according to the principals of patent law, including the doctrine of equivalents.

CLAIMS

1. A direct current electric motor having a reduced inertia rotor, said motor comprising:
 - a housing;
 - 5 a stator affixed to said housing, said stator comprising a plurality of electrically conductive windings and further defining a central cavity; and
 - a rotor mounted within said central cavity and rotatable therein, said rotor comprising a shaft, at least two magnets affixed in a radially spaced manner therefrom, and a rotor core therebetween and rotationally de-coupled from said shaft and said magnets.
- 10 2. The direct current electric motor according to claim 1 wherein an outer periphery of said core is minimally smaller than an inner periphery of said at least two magnets.
3. The direct current electric motor according to claim 1 further comprising at least one bearing supporting said rotor core on said shaft in said
15 rotationally de-coupled manner.
4. The direct current electric motor according to claim 3 further comprising at least one endplate affixing said magnets in said radially spaced relationship from said shaft.
5. The direct current electric motor according to claim 4 wherein
20 said at least one endplate comprises a non-magnetic material.
6. The direct current electric motor according to claim 5 wherein said rotor core comprises a ferro-magnetic material.
7. The direct current electric motor according to claim 6 wherein
25 said rotor core comprises steel.
8. The direct current electric motor according to claim 5 wherein said rotor core comprises a magnetically permeable material.

9. The direct current electric motor according to claim 5 wherein said rotor core comprises a single mass.

10. The direct current electric motor according to claim 5 wherein said rotor core comprises a stacked plurality of wafer-like laminates.

11. The direct current electric motor according to claim 10 wherein each said laminate includes an electrically non-conductive coating thereby electrically insulating each of said plurality of laminates from a next most adjacent laminate.

12. A rotor for a direct current electric motor comprising:
10 a shaft;
a plurality of magnets radially spaced from and rotationally coupled to said shaft, said shaft and said plurality of magnets defining a cannular cavity therebetween; and
a rotor core, positioned within said cannular cavity and rotationally de-
15 coupled from said shaft and said plurality of magnets.

13. The rotor according to claim 12 wherein:
said magnets are arranged to define a cylindrical inner surface;
said rotor core has a substantially cylindrical outer surface; and
said outer core cylindrical surface has a diameter minimally smaller
20 than said magnet inner cylindrical surface thereby permitting free rotation of said core within said cylindrical magnet arrangement.

14. The rotor according to claim 13 further comprising at least one bearing supporting said rotor core on said shaft in said rotationally de-coupled manner.

15. The rotor according to claim 14 further comprising at least one endplate affixing said magnets in said radially spaced relationship from said shaft.

16. The rotor according to claim 15 wherein said at least one endplate comprises a non-magnetic material.

17. The rotor according to claim 16 wherein said rotor core comprises a stacked plurality of wafer-like laminates.

18. The rotor according to claim 17 wherein each said laminate includes an electrically non-conductive coating thereby electrically insulating each of
5 said plurality of laminates from a next most adjacent laminate.

19. A direct current electric motor capable of rapid reversal rates, said motor comprising:
a housing;
a stator affixed within said housing, said stator defining a substantially
10 cylindrical cavity having a central axis; and
a rotor journaled to said housing for rotation about said axis and positioned within said cylindrical cavity, said rotor further comprising:
a shaft having an axis of rotation coincident with said central axis;
a plurality of magnets radially spaced from said shaft and rotationally
15 affixed thereto, said shaft and said plurality of magnets defining a cannular cavity; and
a rotor core within said cannular cavity and rotationally de-coupled from said shaft and said magnets.

20. The direct current electric motor according to claim 19 wherein an outer periphery of said core is minimally smaller than an inner periphery of said
20 plurality of magnets

21. The direct current electric motor according to claim 19 further comprising at least one bearing supporting said rotor core on said shaft in said rotationally de-coupled manner.

22. The direct current electric motor according to claim 21 further
25 comprising at least one endplate affixing said plurality of magnets in said radially spaced relationship from said shaft.

23. The direct current electric motor according to claim 22 wherein said at least one endplate comprises a non-magnetic material.

24. The direct current electric motor according to claim 23 wherein said rotor core comprises a ferro-magnetic material.

25. The direct current electric motor according to claim 24 wherein
5 said rotor core comprises steel.

26. The direct current electric motor according to claim 23 wherein said rotor core comprises a magnetically permeable material.

10 27. The direct current electric motor according to claim 23 wherein said rotor core comprises a single mass.

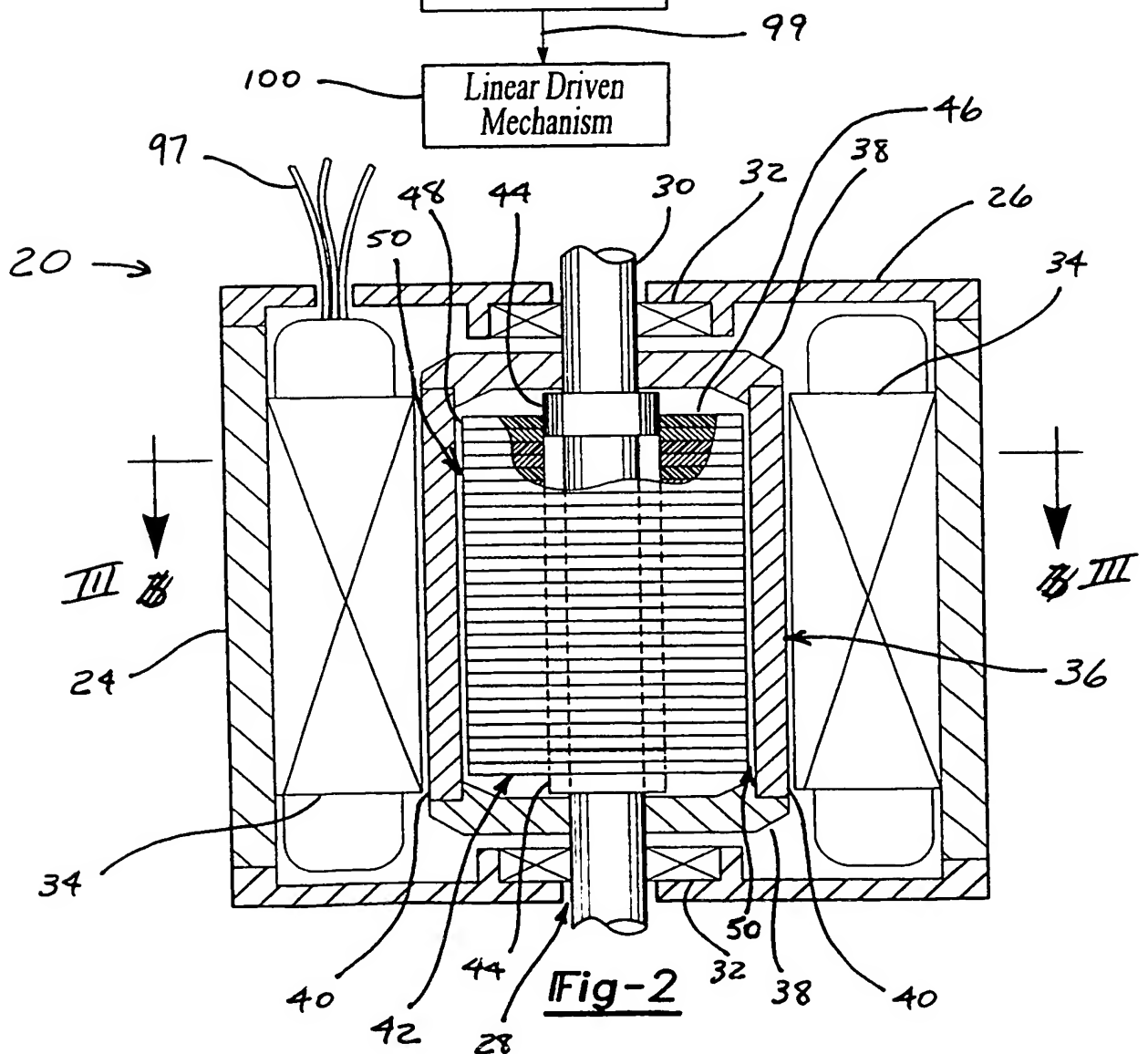
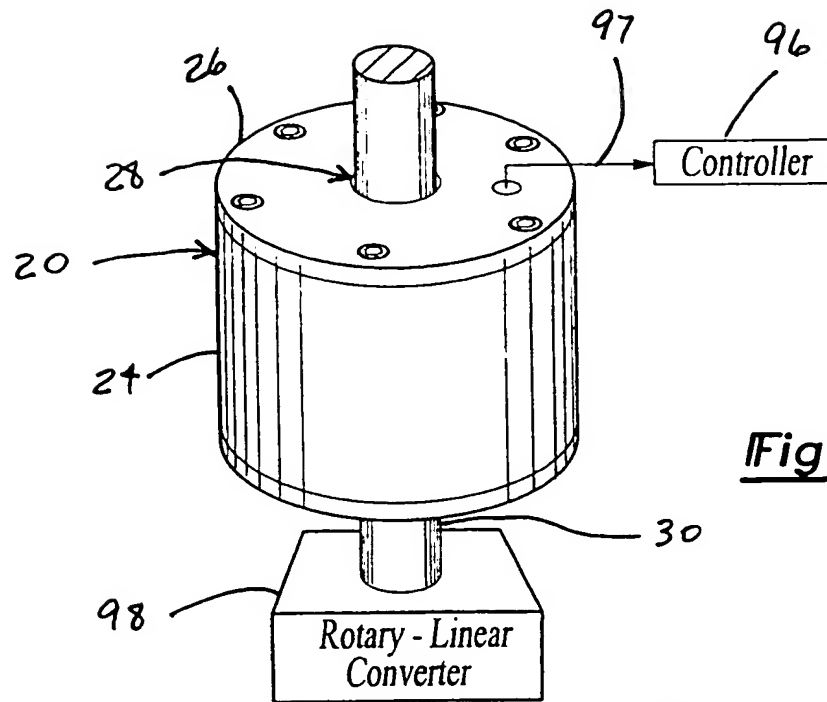
28. The direct current electric motor according to claim 23 wherein said rotor core comprises a stacked plurality of wafer-like laminates.

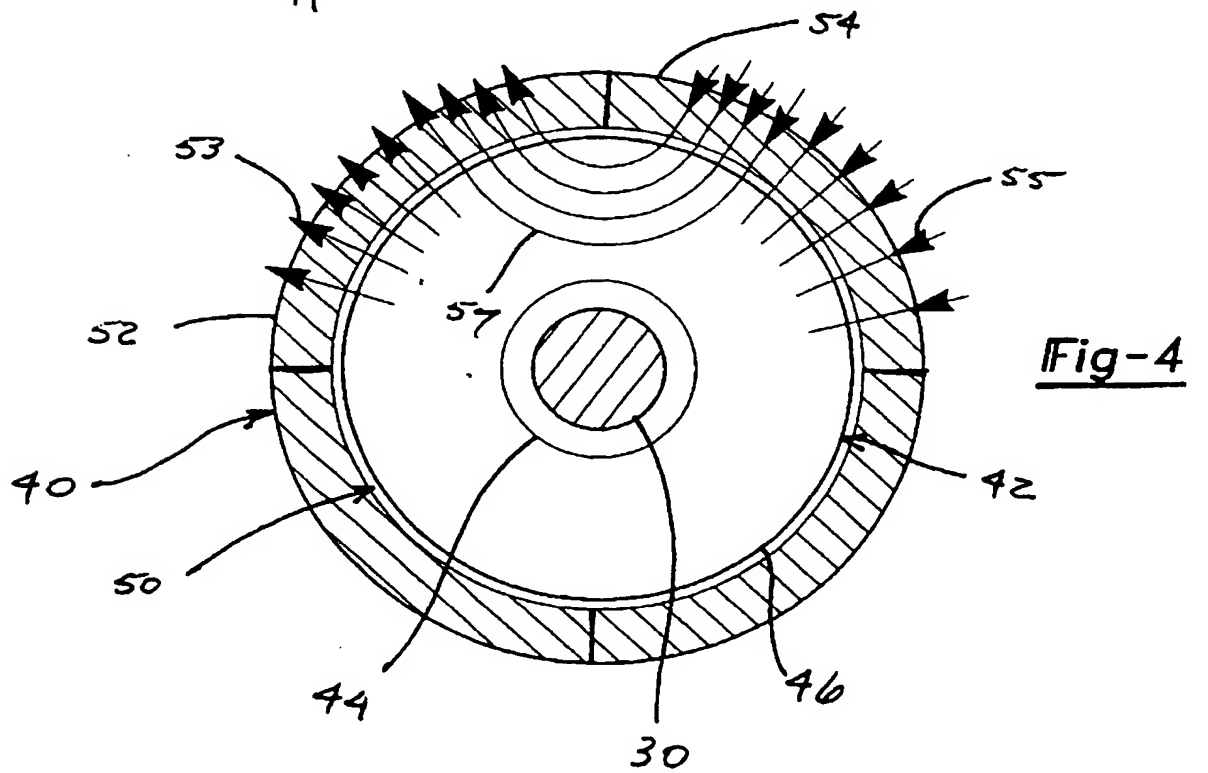
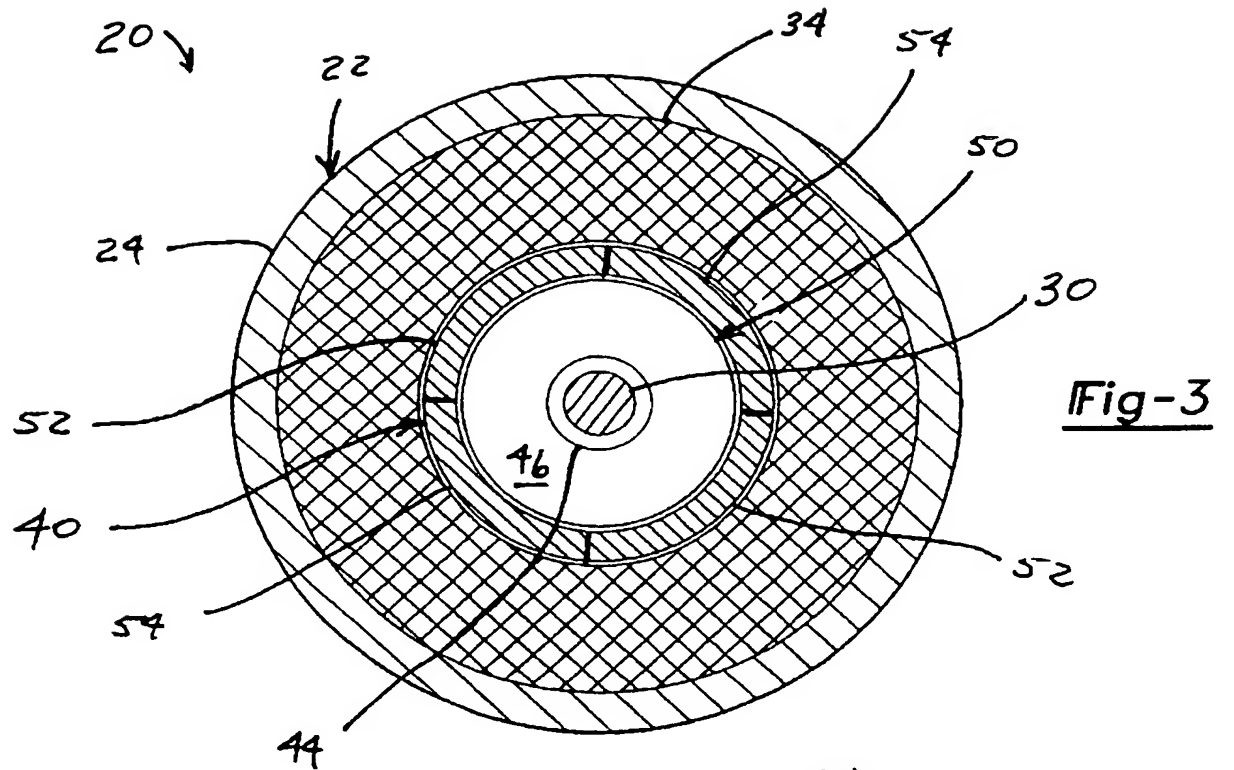
15 29. The direct current electric motor according to claim 28 wherein each said laminate includes an electrically non-conductive coating thereby electrically insulating each of said plurality of laminates from a next most adjacent laminate

30. A method for minimizing the rotational inertia of an electric motor rotor, said method comprising the steps:
20 providing a rotor shaft;
mounting a plurality of magnets about the shaft in a rotationally coupled manner; and
mounting a rotor core about the shaft and within the magnets in a rotationally de-coupled manner.

25 31. The method according to claim 30 further including after said shaft providing step a step of affixing at least one endplate on the shaft; and
said magnet mounting step includes affixing the plurality of magnets to the at least one endplate.

32. The method according to claim 31 wherein the rotor core mounting step includes mounting a bearing between the rotor core and the shaft to achieve the rotational decoupling of the rotor core from the shaft.





INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/33767

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : H02K 29/00, 15/00, 15/02, 15/14
 U.S. CL. : 310/156, 254, 261, 262, 264, 266; 29/596, 597, 598
 According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 310/156, 254, 261, 262, 264, 266; 29/596, 597, 598

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
 NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
 NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	JP 03070457 A (MASATO et al) 26 March 1991 (26.03.1991), Figs. 1 and 5-7.	1-3, 12-14, 19-21, 30 ----- 4-11, 15-18, 22-29, 31-32
Y	US 4,674,178 A (PATEL) 23 June 1987 (23.06.1987) Fig. 1 and col. 4, line 40 - col. 5, line 30.	4-11, 15-18, 22-29, 31-32
A	US 5,783,890 A (MULGRAVE) 21 July 1998 (21.07.1998), Fig. 1.	1-32

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

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Name and mailing address of the ISA/US
 Commissioner of Patents and Trademarks
 Box PCT
 Washington, D.C. 20231

Facsimile No. (703) 305-3230

Authorized officer

Nguyen, Tran

Telephone No. (703) 308-1639 *Rene P. Tran*